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LLNL-CONF-666365

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January 21, 2015

STANFORD GEOTHERMAL WORKSHOP
Stanford, CA, United States
January 26, 2015 through January 28, 2015

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PROCEEDINGS, Fourtieth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 26-28, 2015
SGP-TR-204

Microseismicity During the 2005 Habanero EGS Stimulation in the Cooper Basin of South Australia

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Keywords: Microseismicity, EGS, Cooper Basin

ABSTRACT

We apply the empirical Matched Field Processing (MFP) method to continuous seismic data to detect and determine preliminary locations for more microearthquakes than can be detected using only conventional earthquake detection techniques. We demonstrate that empirical MFP can complement existing catalogs and techniques by using archived seismic information to increase earthquake catalog completeness. Refined earthquake catalogs can then be applied to, for example, subsequent improved b-value studies to investigate the frequency-magnitude relationship of microseismic events during and after stimulation. The empirical MFP method finds new events in the continuous data stream by identifying signals that match pre-defined master templates. We construct representative master templates using known events identified during the 2005 Habanero Stimulation within Cooper Basin, Australia. The master templates are matched to continuous data obtained from the local 8-station borehole seismic array. Of the 8873 events that occurred during the combined 2005 Habanero 1 and Habanero 2 stimulation, 275 events with particularly high signal-to-noise (SNR) are identified and incorporated into this study. During the first week of the Habanero 1 stimulation, 1288 events were identified using traditional earthquake detection methods. The empirical MFP method identified 994 additional events, or approximately 75% more events, during this time frame showing that this advanced microearthquake detection methodology is well adapted for hot fractured rock environments.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

1. INTRODUCTION

The objective of this study is to apply advanced signal processing techniques to detect and locate small microearthquakes that were originally missed or excluded during the 2005 Habanero EGS stimulation in the Cooper Basin of South Australia. Prior to the 2005 stimulation, in November - December 2003 the Habanero 1 well was originally stimulated. The microearthquakes illuminated a narrow horizontal kilometer scale reservoir. Researchers have argued that the resulting reservoir could be either two parallel fracture features (Asanuma et al., 2004) or a single fracture with a vertical extent at the meter scale (Baisch et al., 2006). The site of Habanero 2 was subsequently chosen to be 500 m SSW of Habanero 1.

To identify and locate the new events that may have been originally excluded we apply a technical approach that augments conventional earthquake detection techniques. In this study we apply the empirical Matched Field Processing (MFP) technique to focus the propagating wavefield energy on a suite of candidate source locations (Harris and Kaverna, 2010). MFP sums the signals over the seismic array with complex phase-amplitude weights to steer the network toward a particular location. The phase-amplitude weights are obtained from previously identified, known catalog events. Subsequent microearthquakes can then be matched to the template events, potentially in real-time.

During the combined 2005 stimulation of the Habanero 1 and Habanero 2 wells, approximately 16,000 microseismic events were detected (Baisch et al., 2009). Of these events, only 8886 microearthquakes were of sufficient quality for hypocenter determination (Baisch et al., 2009). The 2005 Habanero 2 stimulation lasted 12 days between 9 - 20 August. The 2005 Habanero 1 stimulation lasted 9 days. Well flow velocity profiles indicated that the majority of the fluids entered the reservoir at approximately 4254 m depth along a major fracture zone.

2. DATA

During the 2005 EGS stimulation, the Habanero seismic network consisted of eight three-component borehole seismic stations equipped with SMART24 24-bit digitizers recording continuously at either 500 Hz or 1000 Hz. Between 08 August 2005 and 12 August 2005, the sample rate was set to 1000 Hz. After 13 August 2005, the sample rate was set for 500 Hz. The deepest seismometer was deployed at the center of the network at a depth of 1783 m with respect to the wellhead. The remaining seismometers were installed between 79 – 370 m in two roughly concentric circles around the reservoir.

3. EMPIRICAL MFP

Our MFP technique is an adaptation of a signal-processing technique originally developed to locate continuous underwater acoustic sources. MFP can steer the array explicitly in the frequency domain using the complex phase and amplitude factors obtained by solving the wave equation through a propagation model. However, it is difficult to develop realistic Earth models to predict the structure of seismic wavefields at frequencies much above a tenth of a Hertz (Harris and Kaverna 2010). An alternative to calculating the wavefield structure across an array is to estimate the structure directly from field calibration data, i.e., previous seismic events. We refer to this strategy as empirical MFP. In empirical MPF, the master templates that are created from the seismograms of previously detected micro-earthquakes thus contain contributions from direct and scattered seismic energy.

Of the 8873 events that occurred during the combined 2005 Habanero 1 and Habanero 2 stimulation, 275 events with particularly high signal-to-noise (SNR) are flagged as master templates. Master events are selected only based on the SNR within the frequency band of interest. No other magnitude, mechanism or location criteria are taken into account. An example master template is shown in Figure 1. It has excellent SNR in the 20 – 30 Hz frequency range that we use in this study to perform the matching operation and any extraneous seismic energy is of significantly lower amplitude than that of the signal itself.

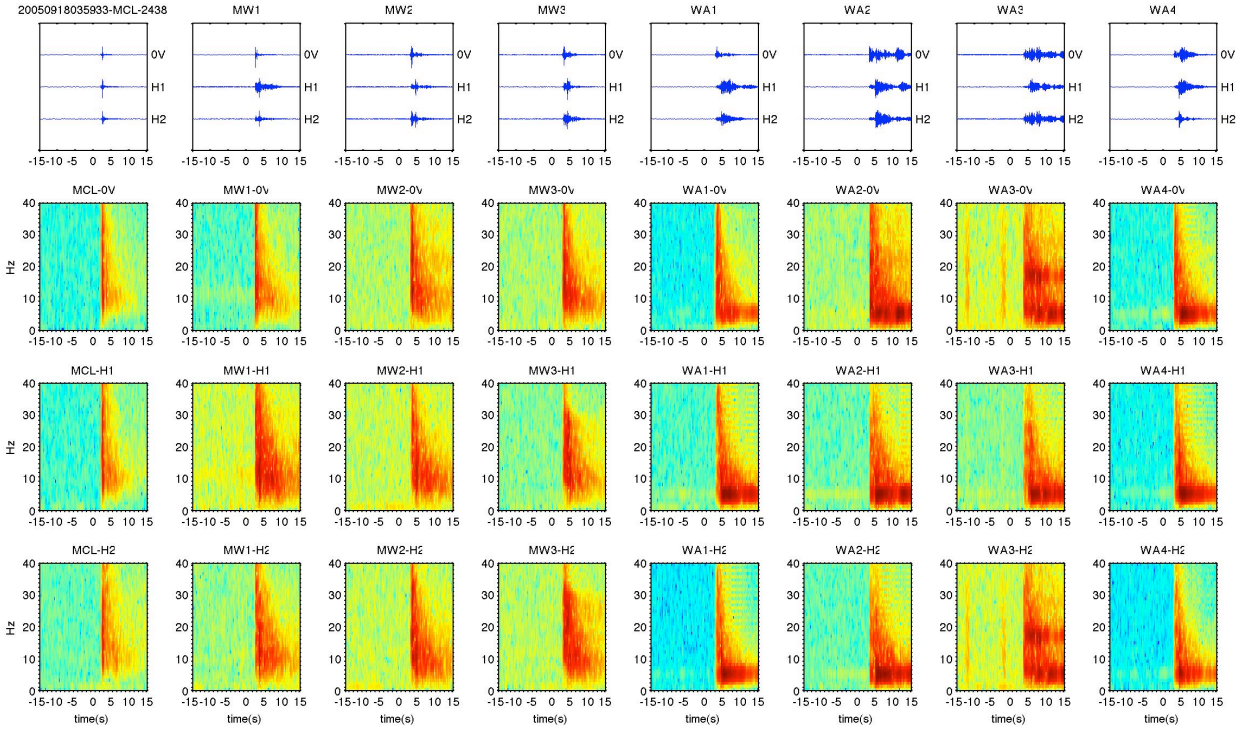

Figure 1: Example of one master event. The first row contains waveform plots at each station. The second, third and fourth rows show spectrograms of the vertical and two horizontal components between 0 – 40 Hz.

Waveform data from all 8 three-component stations is used in the analysis. The empirical MFP code performs the matching operation on the continuous three-component data, stepping forward 1 second at a time. The master templates are derived from information from a 70 second time window centered on the origin time of the master event. We apply the template matching operation across the first week of the Habanero 1 2005 stimulation. During this time period, 1288 events were originally identified using traditional earthquake detection methods (Baisch et al., 2009).

4. RESULTS AND DISCUSSION

The empirical MFP methodology described above was applied to the first week of continuous seismic data from the Habanero 1 2005 stimulation. The empirical MFP method identified 994 additional events, or approximately 75% more events, during this time frame showing that this advanced microearthquake detection methodology is well adapted for hot fractured rock environments. The empirical MFP matching operation runs very efficiently on a desktop computer. One day of data was matched to the 275 master templates in approximately 6 minutes. Additional improvements in speed could be accomplished with further analysis to verify that the quality of the master template is not degraded.

5. CONCLUSIONS

In this study we examine one week of continuous seismic data from the first week of the 2005 Habanero 1 stimulation. We identify 994 additional events, or approximately 75% more events than were identified in the original earthquake catalog. Analysis of the amplitude of these events shows that the new events are generally of lower magnitude than the original events, as would be expected. Further investigation of the spatio-temporal map is necessary to determine if the master events that identified the most new microearthquakes during the first week of stimulation continue to identify significantly more events than their neighbors and if events are identified even during the stimulation of the Habanero 2 well.

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